Hydrological and geological constraints on timescales of magmatic-hydrothermal ore deposits

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Chemical enrichment of metals in magmatic-hydrpthermal ore deposits majorly depends on the physical hydrology of fluids flowing through rocks. The respective geological setting and associated physical hydrology play a decisive role in forming distinct ore deposit types, including volcanogenic massive sulfide deposits at mid-ocean ridges or submarine arc volcanos, porphyry deposits in continental arcs, and epithermal deposits. Simulation results from a numerical process model for thermohaline convection in conjunction with a dynamic permeability model are used to constrain the timescales of ore formation. Thermal convection, volatile expulsion, and salt-water dynamics are first-order hydrological components with different intrinsic timescales, and different combinations or successions of these general patterns can help to constrain the timing and duration of particular ore-forming systems.

The physical behavior of hydrothermal systems can be counterintuitive, because of the nonlinear properties of fluids and rocks as a function of pressure, temperature and composition. In porphyry copper systems, mineralization is localized by a self-stabilizing hydrological front, located at the transition from brittle to ductile rock behavior and controlled by the heat balance between an external convective cooling engine and an overpressured magmatic fluid plume. Above this hydrological divide, magmatic and meteoric fluids mix on ascent to the surface, providing a mechanism for the transition from porphyry to epithermal deposits. In mid-ocean ridge hydrothermal systems, focused warm downflow in the immediate vicinity of hot upflow zones may be a more efficient mechanism for metal leaching than broad-scale lateral infiltration of seawater, promoting ore-formation in Cyprus-type massive sulfide deposits. In submarine magmatic-hydrothermal systems, phase separation can lead to a decoupling of vapor-dominated venting during relatively short periods of magmatic fluid expulsion, leading to the formation of Au-rich chimneys, and brine-dominated venting during convection in an extended waning stage, leading to the formation of base-metal deposits.

All simulations of magmatic-hydrothermal ore formation indicate timescales in the order of a few 10^2 to 10^5 years for single mineralization events.